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The diversity of moss flora of Katowice town (S Poland)

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Abstract – The results of bryological studies that were conducted on the territory of Katowice are presented. Katowice is the largest town in the main Polish industrial region (Silesia Province). The goal of the paper is to evaluate the impact of human pressure and the spatial structure of a town on the distribution of moss species. A great deal of habitat diversity is reflected in the quite high species richness. The moss flora includes 192 species, from which 14 are considered endangered in the national red list, seven are regionally endangered in the Silesia Province (four of those included in the former list and another three), and 48 taxa are under legal protection by the Polish government (36 not included in either of the former lists). In heavily urbanized areas of the city the number of species usually does not exceed 20 in one square kilometer. In squares that were more differentiated in regard to habitat conditions and in those with a greater forest cover, species richness amounted to almost 60. Some ecological aspects are discussed, e.g. the spatial polarization of calciphilous and acidophilous bryoflora.

Bryophytes / Urban areas / Human impact

INTRODUCTION

In recent decades towns, which comprise unique ecological-spatial systems, have been subjected to detailed floristic-ecological research (e.g. Gilbert, 1971; Seaward, 1979; Mazimpaka *et al.*, 1988, 1993; Sukopp, 1992; Pokorny *et al.*, 2006 – and cited literature). Their objective was to determine changes that occurred in the formation of "urban floras" and the characteristics of their biotopes. In the case of vascular plants, the aspect of local floristic richness is highlighted, especially when compared to adjacent rural areas, which are usually poorer in the number of species (Starfinger & Sukopp, 1994; Pyšek, 1998; Wania *et al.*, 2006). One of the reasons for this situation is the wider array of habitats and the higher abundance of alien species. As far as urban bryofloras are concerned, the unwanted phenomena that lead to the impoverishment of flora are mainly discussed (Gilbert, 1971; Seaward, 1979; Fudali, 1997). Many studies have focused on the influence of human activity upon bryophyte distribution in urban areas (e.g. Mazimpaka *et al.*, 1988, 1993; Lara *et al*., 1991; Lo Giudice *et al.*, 1997; Vanderpoorten, 1997; Grdović & Stevanović, 2006; Sabovljević & Sabovljević, 2009). Also in the Katowice town the bryophytes were studied in the years 1998-2000 by Fojcik & Stebel (2001). They found 176 moss species, 34 liverworts and 1 hornwort.

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The range and methods that have been used in the studies that have been conducted in the towns may refer to "urban flora" or "flora of the town" (Sukopp & Wittig, 1993; Sudnik-Wójcikowska, 1998). The first concept refers to species that are related only to the most typical urban areas and habitats. As a rule the most resistant and tolerant bryophytes species are found there. "Flora of the town" comprises all of the flora within the bounds of the town, often with rare and endangered species (in the region or even on a country-wide scale). The studies of the second kind are comparatively rarely conducted and the present paper is one of these.

Katowice is the largest town within the Upper Silesian Industrial District – the main Polish industrial region (Silesia Province). The whole area covers 165 km^2 and has about 350000 inhabitants. Its relief consists of a group of rounded hills (rarely exceeding 300 m a.s.l.), that are composed of Pleistocene deposits. The majority of soils is podsolic and pseudopodsolic and is formed by loamy sands of a glacial origin. Locally, small patches of alluvial, peaty and boggy soils occur in natural river valleys. Its climate is temperate. There is an annual precipitation of 779 mm on average and the annual mean temperature is 7-8°C (Szaflarski, 1976). The vegetation and flora of Katowice have been almost completely transformed by the economic activities. Natural and seminatural plant communities remain only in forests enclaves (e.g. a beech forest reserve, Murckowski Forest or a peat bog, Płone Bagno). Not long ago (in the 1990s) among other things, nine coal mines and four smelting works were located in Katowice. Some of them were closed, the others were modernized, but in spite of this the Katowice is still one of the most polluted areas in the country (this refers to the air, soil and water).

There are four main types of land-use complexes in the spatial structure of Katowice. Downtown makes up a comparatively small part of this town. It is characterized by densely arranged tenement-house buildings and large areas that are covered with concrete and asphalt. The suburbs include the majority of the northern part of the town with apartment blocks and residential homes and a greater number of municipal parks and squares. Fields, meadows and abandoned arable lands prevail in the agricultural complex (low buildings are sparsely arranged). Forests cover about 40% of the area. Almost all of the tree stands are dominated by *Pinus sylvestris* L. and *Quercus robur* L. Natural fragments of water streams and ponds with fens and peat-bogs remain only in the forests.

The goal of the paper is to evaluate the impact of human pressure and the spatial structure of a town on the distribution of local moss flora.

MATERIALS AND METHODS

It was written based on studies carried out on the territory of Katowice (Fojcik & Stebel, 2001 and new data). The area was divided into one kilometer squares based on the ATMOS-squares grid system (Ochyra & Szmajda, 1981). The study area encompassed 204 squares in which a floristic inventory was done. During the sampling, habitat characteristics were checked and recorded.

The frequency of species occurrence was determined according to distinguished classes (proposed by the authors): species recorded in 1-5 squares –

very rare; 6-10 squares – rare; 11-25 squares – fairly frequent; 26-50 squares – frequent; 51-80 squares – very frequent; in more than 80 squares – common.

For ecological analyses the following indicator values were used (Düll, 1992), differentiation of species into shading species (L = 1-3) and light-demanding (L = 7-9), as well as acidophilous (R = 1-3) and calciphilous species (R = 7-9). In order to determine the floristic value of particular squares, an indicator of floristic value was employed. It is the sum of the coefficients of species rarity that is recorded in a given square (Géhu, 1979; Loster, 1985):

$$W_f = \sum W_r = \sum \frac{N - n}{N}$$

where: N = total number of studied squares; n = number of squares where the presence of a given species has been recorded.

The nomenclature of mosses follows Ochyra *et al.* (2003) and that of flowering plants follows Mirek *et al*. (2002). Threat categories in Poland follow Żarnowiec *et al.* (2004), according to old categories of IUCN (1978) (all listed species are discussed as threatened): EX – extinct, E – endangered, V – vulnerable, R – rare, I – indeterminate. Threat categories in a region (of Silesia Province) follow Stebel *et al.* (2011), with actual IUCN (2001) categories: EX – extinct, CR – critically endangered, EN – endangered, VU – vulnerable. Values of Spearman rank correlation coefficient (with $p < 0.05$) were computed using STATISTICA software (version 10) (Sokal & Rohlf, 1995).

RESULTS

The bryoflora of Katowice includes 192 moss species (Appendix 1), 176 of them were published (Fojcik & Stebel, 2001), the rest were found after 2006. In this paper 16 new moss species are added to the catalogue of Katowice and also new stations of earlier noted bryophytes have been found. The most numerously represented among 34 families are: *Brachytheciaceae* (22 species), *Sphagnaceae* (19), *Bryaceae* (18), *Amblystegiaceae* (18) and *Pottiaceae* (16). The largest group consists of very rare species (83 species, more than 40%). Only 29 (15%) species were common ones. Among these: *Amblystegium serpens* (Hedw.) Schimp., *Barbula convoluta* Hedw., *B. unguiculata* Hedw., *Brachythecium rutabulum* (Hedw.) Schimp., *Ceratodon purpureus* (Hedw.) Brid. and *Funaria hygrometrica* Hedw. are the most frequent.

In the afforested areas of Katowice, man-made habitats play a crucial role. Among them the highest moss richness was found on the roadsides and unsurfaced roads (54 mosses), concrete walls (44), lawns (37) and urban wastelands (27). The number of species inhabiting such sites is limited and the most resistant and tolerant species prevail. These are usually common ubiquistic, light-demanding mosses, e.g. *Ceratodon purpureus*, *Barbula convoluta*, *B. unguiculata*, *Bryum argenteum* Hedw., *B. caespiticium* Hedw., and *Brachythecium rutabulum*. Economic activity and the initial man-made habitats that are associated with it enhance the penetration of small therophytes, e.g. *Discelium nudum* (Dicks.) Brid., *Dicranella varia* (Hedw.) Schimp. and *Tortula truncata* (Hedw.) Mitt. For instance, *Discelium nudum* was mainly observed in an old excavation of clay.

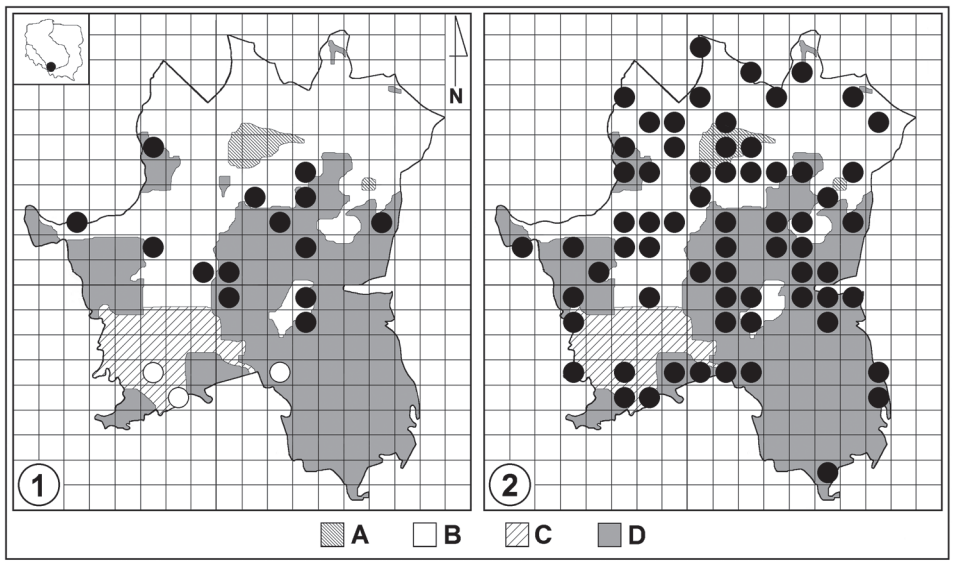
The largest number of species was noted in forest habitats; in terrestrial ones 87 in deciduous and 62 in coniferous forests. This is a relatively high number due to the high degree of the degeneration of the forests. The moss layer is usually poorly developed or does not exist at all. The forest floor often is covered by a layer of slowly decomposing leaves or overgrown by dense sod formations (caused mainly by species of the *Calamagrostis* Adans. genus and *Carex brizoides* L.). In this connection dead wood often plays an essential role in the maintenance of the diversity of bryoflora. Sixty species were recorded on decaying wood in total. Locally, it is the only refuge for mosses that have been forced out of terrestrial habitats due to various degeneration processes. Their only stands, owing to this kind of habitat, have among the others: *Dicranum polysetum* Sw. *ex* anon., *Leucobryum glaucum* (Hedw.) Ångstr., *Ptilium crista-castrensis* (Hedw.) De Not. and *Thuidium tamariscinum* (Hedw.) Schimp. An especially frequent epixylic species on the territory of Katowice is *Callicladium haldanianum* (Grev.) H.A. Crum, a moss included in the European red-list (Schumacker & Martiny, 1995) as Regionally Threatened.

Fifty-six species occurred on tree bark. Bases of trees (up to one meter) were most frequently occupied by mosses ascending from terrestrial habitats. The highest number of epiphytes were observed on oaks, birch and poplars. Those most frequently observed on the bark of various trees were: *Amblystegium serpens* (9 species of trees), *Brachytheciastrum velutinum* (Hedw.) Ignatov & Huttunen (6 species of trees), and *Brachythecium rutabulum*, *Callicladium haldanianum*, *Ceratodon purpureus*, *Dicranum scoparium* Hedw., *Hypnum cupressiforme* Hedw., *Orthodicranum montanum* (Hedw.) Loeske, *Plagiothecium curvifolium* Schlieph. *ex* Limpr., *Plagiothecium laetum* Schimp. (5 species of trees).

Within recent years there has been an increase in the number of stands of light-demanding epiphytic species. Some of them were known only from few localities until 2001 (Fojcik & Stebel, 2001), but later the number of their new stations increased, e.g. *Orthotrichum pumilum* Sw. *ex* anon. (Fig. 1). The others, like *Leskea polycarpa* Hedw., *Orthotrichum affine* Schrad. *ex* Brid., *O. patens* Bruch *ex* Brid., *O. rogeri* Brid., *O. stramineum* Hornsch. *ex* Brid., *O. striatum* Hedw., *Syntrichia latifolia* (Bruch *ex* Hartm.) Huebener, *Ulota bruchii* Hornsch. *ex* Brid. and *U. crispa* (Hedw.) Brid., were noted for the first time only after 2006.

The lack of natural rock outcrops limits the occurrence of epilithic species mainly to anthropogenic rock-like habitats (e.g. concrete walls, rubble). Forty-four mosses were observed on such substratum. They are usually dispersed over the entire Katowice area, e.g. *Rhynchostegium murale* (Hedw.) Schimp. (Fig. 2). The most frequent of them were: *Amblystegium serpens*, *Brachythecium rutabulum*, *Ceratodon purpureus*, *Dryptodon pulvinatus* (Hedw.) Brid., *Rhynchostegium murale*, *Sciuro-hypnum populeum* (Hedw.) Ignatov & Huttunen and *Tortula muralis* Hedw. On natural substratum (e.g. erratic blocks and stones) 26 taxa were noted. The rarest species from epilithic ones are *Codriophorus acicularis* (Hedw.) P. Beauv., *Dryptodon muehlenbeckii* (Schimp.) Loeske and *Sciuro-hypnum plumosum* (Hedw.) Ignatov & Huttunnen.

Hydrophytic and hygrophytic mosses occur mainly in forests where natural fragments of water streams and ponds with fens and peat bogs remains. Species like, e.g. *Campylium polygamum* (Schimp.) Lange & C.E.O. Jensen, *C. stellatum* (Hedw.) Lange & C.E.O. Jensen, *Plagiomnium ellipticum* (Brid.) T.J. Kop. and *Warnstorfia exannulata* (Schimp.) Loeske were found in such places. Moreover, up to 19 of peat mosses were noted, e.g. *Sphagnum denticulatum* Brid., *S. magellanicum* Brid., *S. papillosum* Lindb., *S. riparium* Ångstr. and *S. russowii* Warnst.



Figs 1-2. Distribution of some species mosses in the Katowice town in the main types of land use (A – downtown, B – suburbs, C – agricultural area, D – forest). **1.** *Orthotrichum pumilum* (white dots: localities in 2001; black dots: localities in 2011 (according Fojcik & Stebel (2001) and new data) (in the upper left corner the localization of Katowice town in Polish territory is given). **2.** *Rhynchostegium murale*.

The number of moss species noted in particular squares on the territory of Katowice is quite differentiated. It is strongly correlated with the degree of the forestation of these squares (the correlation between the percentage of forest areas and the number of species in particular cartogram units amount to 0.75). On urbanized sites (mainly the northern part of the city) the number of species does not exceed 20. The common urban specialists such as: *Barbula convoluta*, *Bryum argenteum*, *B. caespiticium*, *Ceratodon purpureus* and *Funaria hygrometrica* dominate there. In squares where the area of forest habitats varied between 1% and 10%, there were on average 20 species. In forested areas with more diversified habitats, the mean number amounted to 42 species (species richness may even amount to about 60). Generally, squares that are poorer in the number of species are the most frequent; the number of recorded mosses exceeded 50 in only 16 squares.

The value of floristic quality index for particular squares ranges from 0.53 to 34.14. Comparing the mean value of the floristic quality of the squares representing various types of land use complexes, it is apparent that the intensity of land use reduces the value of this index (Table 1). The squares with the highest value of floristic quality are mainly completely or partially forested (Fig. 3).

Ecological analyses of the mosses as light indicator values showed that light-demanding species make up 49% of the whole bryoflora. The presence of typical shadow-tolerant taxa was restricted to only five species: *Sciuro-hypnum oedipodium* (Mitt.) Ignatov & Huttunen, *Plagiomnium ellipticum*, *Plagiothecium latebricola* Schimp., *Rhizomnium punctatum* (Hedw.) T.J. Kop. and *Tetraphis pellucida* Hedw. The contribution of calciphilous and acidophilous species in the bryoflora that were analyzed amounted to 24% and 33% respectively. Their contributions in particular study squares is presented in Figs 4 and 5.

Table 1. Species number and floristic value of the cartogramme units in the main types of land-use complexes in Katowice town

Type of land-use complex	*Number of squares**	*Medium number of species*	*Medium quality of floristic value*
Downtown	1	11	2.21
Suburbs	34	18	6.07
Agricultural area	6	15	4.55
Forest	15	43	22.64

* Only squares with above 50% of area of particular type of land-use complex were taken into consideration

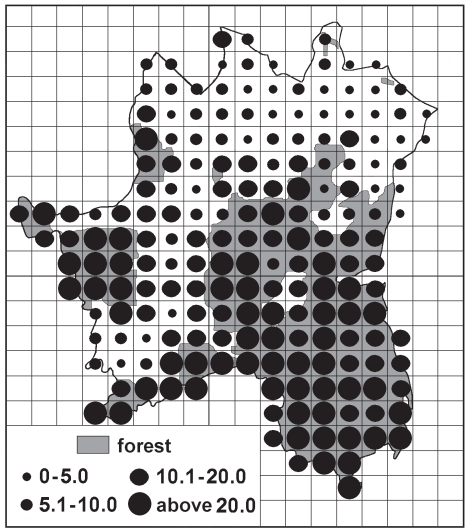
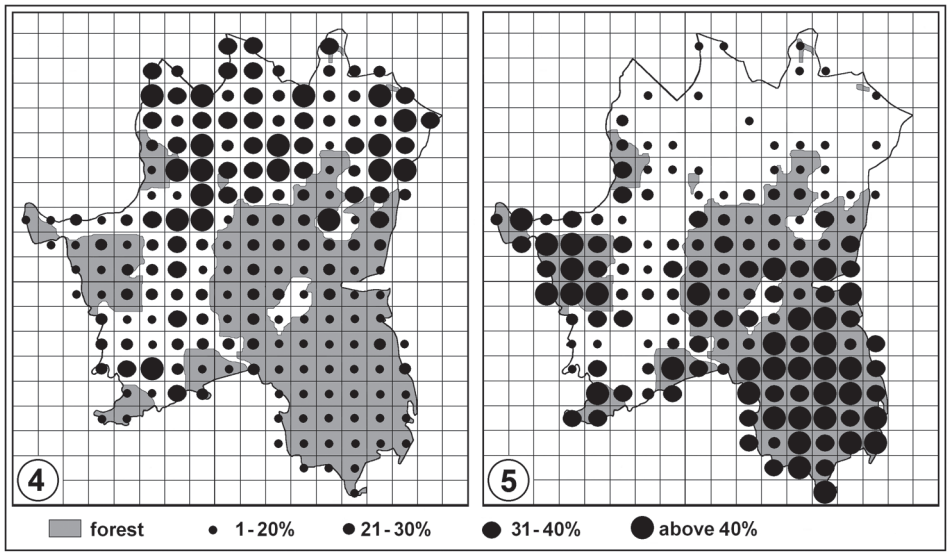


Fig 3. Floristic value of particular cartogramme units in forested and unforested areas in Katowice town.



Figs 4-5. Percentage of species in forested and unforested areas in Katowice town according their ecological preferences. **4.** Calciphilous species. **5.** Acidophilous species.

Many of the mosses that were recorded in Katowice are counted as rare and endangered species on the scale of region and country. Fourteen species from the Polish red list of threatened mosses were recorded: *Amblystegium radicale* (P. Beauv.) Schimp.) (R), *Anacamptodon splachnoides* (Froel. *ex* Brid.) Brid. (E), *Discelium nudum* (V), *Helodium blandowii* (F. Weber & D. Mohr) Warnst. (E), *Orthotrichum patens* (R), *O. rogeri* (EX), *O. stramineum* (V), *O. striatum* (V), *Philonotis caespitosa* Jur. (R), *Sphagnum papillosum* (I), *Syntrichia latifolia* (R), *Trematodon ambiguus* (Hedw.) Hornsch. (R), *Ulota bruchii* (V) and *U. crispa* (V). Seven species are regionally endangered in the territory of Silesia Province, four included in the mentioned national red list: *Anacamptodon splachnoides* (CR), *Discelium nudum* (CR), *Helodium blandowii* (CR), and *Trematodon ambiguus* (CR); and another three: *Campylium polygamum* (VU), *Ptilium crista-castrensis* (VU) and *Sphagnum magellanicum* (VU). Amongst the mosses that are under legal protection (according to the Disposition by the Minister of Environment from 2012), there are 48 taxa (36 of which are not included in any of the two former lists), 27 that are strictly protected and 21 that are partially protected (Appendix 1). The most interesting findings were stands of:

– *Anacamptodon splachnoides* – one of the rarest epiphytes of Polish bryoflora, most of stations that were noted before actually did not exist (Bednarek-Ochyta *et al*., 1994; Fojcik & Stebel, 2001).

– *Discelium nudum* – recently considered to be an extinct taxon in the territory of the country (Stebel, 1997a; Fojcik & Stebel, 2001).

– *Oligotrichum hercynicum* (Hedw.) Lam. & DC. – a subarctic-subalpine species, until now known in Poland only in mountainous regions; the only lowland station was noted in Katowice (Fojcik & Stebel, 2001).

– *Orthotrichum rogeri* – a species regarded as extinct in Poland, the only actual station is in the town of Katowice (Stebel, 2010, Ellis *et al*., 2011).

– *Trematodon ambiguus* – also one of the rarest elements of the Polish bryoflora (Stebel & Ochyra, 1997; Fojcik & Stebel, 2001).

DISCUSSION

Urbanization leads to the decay of many natural and semi-natural habitats or a decrease in their area. Specific mesoclimatic conditions, soil and water, as well as air pollution are additional factors that limit the presence of many plants, especially mosses. Katowice, with 192 species in an area of 165 km^2, belongs to the group of towns with a relatively rich bryoflora. A comparison with e.g. Oświęcim with an area of 30 km^2 and 114 moss species (Żarnowiec, 1996), Szczecin, with 210 km^2 and 152 species (Fudali, 1997) and Belgrade, with 360 km^2 and 187 species (Sabovljević & Grdović, 2009) proves this. According to many sources the number of mosses in large towns (more than 150 km^2) usually exceeds 150 (Schaepe, 1986; Müller, 1993; Vanderpoorten, 1997; Fudali, 1998; Sabovljević & Grdović, 2009). This is associated with a high degree of habitat diversity and the presence of semi-natural vegetation enclaves, some of which having features that are similar to natural ones.

The strong transformation of habitats in urbanized areas leads to their uniformity. Typical man-made biotopes are formed, and subsequently inhabited by synanthropic plants. Among the species of anthropogenic urban habitats in Katowice, the most frequent were: *Amblystegium serpens*, *Barbula convoluta*, *Ceratodon purpureus*, *Bryum argenteum*, *B. caespiticium*, *Brachythecium*

rutabulum, *Dryptodon pulvinatus*, *Funaria hygrometrica*, *Schistidium apocarpum s.l.* and *Tortula muralis.* In many publications, a similar group of species is classified as urban bryophytes in general (or urban specialists) (e.g. Ballesteros & Ron, 1985; Vanderpoorten, 1997; Fudali, 1998; Bezgodov, 2000; Delgadillo & Cárdenas, 2000; Pokorny *et al*., 2006; Isermann, 2007; Kirmaci & Agcagi 2009; Sabovljević & Grdović, 2009; Sabovljević & Sabovljević, 2009).

In the majority of large towns there is an analogous diversity in the complexes of land use such as: the city center, industrial areas, suburbia, rural and forest areas. Specific forms and degrees of vegetation transformation can be observed within each of these complexes. City centers areas are usually characterized by compact and dense constructions and large areas are covered by asphalt and concrete. Also in Katowice the poorest bryoflora occurs there and often there are fewer than 20 species per one km^2. Industrial areas have similar biotopic limitations. Suburbia and rural areas are characterized by a higher habitat diversity, which is reflected in higher species richness. The most diversified bryoflora obviously occurs in forested areas or in large park complexes (Fudali, 1994; Grdović & Stevanović, 2006; Drugova, 2010). This is the effect of the general nature of vegetation, which is frequently accompanied by the presence of water courses and reservoirs that very often have a natural character as well as swamps or mires. For these reasons in Katowice the squares with the highest species richness, more than 50, were located in the forested part of the town, which is similar to Szczecin (also more than 50 species) (Fudali, 1996) and Brussels (there were more than 60 species) (Vanderpoorten, 1997).

An artificial concrete rock-like substratum is a very important anthropogenic habitat for bryophytes and because of this epilithic mosses are abundantly represented in urban bryofloras even in a case of a lack of natural rock outcrops, e.g. 44 species in Katowice (Fojcik & Stebel, 2001), 41 in Braunschweig (Schrader, 1994), and 38 in Szczecin (Fudali, 1998). Among the typical epilithic species the most frequent and abundant are: *Dryptodon pulvinatus*, *Rhynchostegium murale*, *Schistidium apocarpum* s.l. and *Tortula muralis*. In addition, mosses which have a wider ecological spectrum, e.g. *Amblystegium serpens*, *Brachythecium rutabulum*, *Bryum argenteum* and *Ceratodon purpureus*, often grow like epilithic ones.

An interesting phenomenon observed in the area of Katowic is the spatial polarization of calciphilous and acidophilous bryoflora. Calciphilous species play a significant role in the urbanized regions. This is the result of the presence of favorable habitats that are characterized by a higher pH. This concerns both soils (the alkalizing influence of concrete and gravel intercalations and the fall of dust from steelworks) and a concrete stratum (walls, rubble, etc.). The incidence of acidophilous species is much higher in forests. This is connected with the presence of coniferous forests, mires and other habitats that are appropriate for acidophilous species, e.g. epiphytic ones (the bark of oaks, birches, beeches) and epixylic ones (decaying wood). It should be stressed that the general number of species in a square influenced this division (there were more species including many acidophilous taxa in forests while beyond the forests the number of species was lower although many of them preferred an alkalic substratum).

Air pollution and the acidification of rain in urban areas are undoubtedly factors that resulted in a higher frequency of some acidophilous mosses, especially the epiphyte and epixylic ones (Greven, 1992; Söderström, 1992; Fudali, 1997; Stebel, 1997b, Bates & Preston, 2011). This is confirmed by the studies conducted in Katowice. Such species as *Dicranoweisia cirrata* (Hedw.) Lindb., *Hypnum pallescens* (Hedw.) P. Beauv., *Orthodicranum montanum* were recorded in forests

relatively frequently. *Orthodicranum tauricum* (Sapjegin) Smirnova also had a few stands; it is a typical representative of this group that was recently considered to be a rare element in the whole country, but which nowadays is spreading in Poland and neighbouring countries (Stebel *et. al*., 2012). Moreover, acidophilous epixylic (also epiphytic) *Callicladium haldanianum* is now very frequent in the forests in the Katowice area (noted in 59 squares). It is interesting that in Poland up to the mid 20th century this species was known from scattered localities, but since the 1990s the number of records has clearly increased (Stebel, 2013).

The pro-ecological politics that have been conducted in recent decades has led to a considerable limitation of air pollution emission. Therefore in Katowice and in some other towns the spreading of rare non-forest epiphytes from the genus *Orthotrichum* and *Ulota* are noted, e.g. in Brussels (Vanderpoorten, 1997), London (Duckett & Pressel, 2009), Wrocław (Fudali, 2012). They were unobserved for a long time and the actual trend probably reflects an improvement in air quality, mainly a decline of SO_2, in the last few decades. It is interesting that in Katowice this kind of epiphytes exhibit a distinct preference towards inhabited tree species. The most commonly and abundantly inhabited phorophytes were poplars and willows (with a higher pH of the bark). Such preferences were also observed in London (Adams & Preston, 1992), Kiev (Dymytrova, 2009) and Wrocław (Fudali, 2012). The higher pH of bark may buffer the influence of negative habitat factors (e.g. the acidification of rain), which enhances the probability of the colonization success of epiphytes. High pH allows sensitive species to survive even in the city centers by altering sulphur ions into a less toxic form (Gilbert, 1971). Hence, in Katowice or Wrocław (Fudali, 2012), some typical epiphytes like *Orthotrichum diaphanum* Schrad. *ex* Brid. or *Pylaisia polyantha* (Hedw.) Schimp. move in to replacement habitats with higher pH levels, e.g. concrete walls.

Not only in Katowice rare species have considerable incidence in the structure of bryoflora in towns. Despite differences in the criteria that have been adopted for distinguishing species, they make up about 50%, e.g. in Katowice 104 of 192 species, in Belgrade 91 of 185 species, and in Brussels 91 of 185 species. Many protected and endangered species have their stands in the town areas. The most precious elements are species on the red lists. In Katowice there are 14 species from the country's red list, similarly as in Belgrade (Sabovljević & Grdović, 2009). Also species from the European red-list (Schumacker & Martiny, 1995) can be found, e.g. *Anacamptodon splachnoides* (Katowice), *Callicladium haldanianum* (Belgrade, Katowice, Szczecin), *Ephemerum stellatum* H. Philib. (Brussels) or *Hilpertia velenovskyi* (Schiffn.) R.H. Zander (Belgrade).

Bryophytes usually react negatively to the processes of urbanization. Their higher local diversity in urban areas might be an indicator of precious environmental sites that deserve legal protection as biodiversity centers (Pyšek, 1998; Kent *et al*., 1999). However, it must be remembered that tendencies in nature conservation in towns require an approach that is different from the traditional one. Wastelands or colliery waste tips can be interesting in regard to flora that deserves protection (Greenwood & Gemmell, 1978; Goode, 1989; Tokarska-Guzik, 1991). Such places also can be refuges for rare local moss species, e.g. in Katowice *Weisia controversa* Hedw. occurs only in the wastelands around steelworks on soils with high pH (7-8).

Urban areas have proved to be good study plots for the observation of changes in vegetation that is under human impact. This also refers to moss flora. However, it is necessary to standardize research methods so that they would facilitate a wider comparison and interpretation of the data that is obtained.

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REFERENCES

DAMS K.J. & PRESTON C.D., 1992 — Evidence for the effects of atmospheric pollution on bryophytes from national and local recording. *In*: Harding P.T. (ed.), *Biological recording of changes in British wildlife.* ITE Symposium 26. London, Her Majesty's Stationery Office, pp. 31-43.

BALLESTEROS T. & RON M.E., 1985 — Contribution to the study of the bryophytic flora of the city of Toledo. *Anales del jardín botánico de Madrid* 42 (1): 87-91.

BATES J.W. & PRESTON C.D., 2011 — Can the effects of climate change on British bryophytes be distinguished from those resulting from other environmental changes? *In:* Tuba Z., Slack N.G. & Stark L.R. (eds.), *Bryophyte ecology and climate change*. Cambridge, Cambridge University Press, pp. 371-407.

BEDNAREK-OCHYRA H., OCHYRA R. & SZMAJDA P., 1994 — *Anacamptodon splachnoides* (Brid.) Brid. *In*: Ochyra R. & Szmajda P. (eds.), *Atlas of the geographical distribution of spore plants in Poland. Series V. Mosses (Musci)*. IX. Kraków, Poznań, W. Szafer Institute of Botany, Polish Academy of Sciences and Adam Mickiewicz University, pp. 37-40.

BEZGODOV A.G., 2000 — Mosses of the Perm city (Middle Ural, Russia). *Arctoa* 9: 141-150.

DELGADILLO M. C. & CÁRDENAS S. Á., 2000 — Urban mosses in Mexico City. *Anales del Instituto de Biologia Universidad Nacional Autónoma de México, Serie botánica* 71 (2): 63-72.

DRUGOVA T.P., 2010 — Mosses of Monchegorsk City (Murmansk province, north-west Russia). *Arctoa* 19: 165-170.

DUCKETT J. & PRESSEL S., 2009. London's changing bryophyte flora. *Field bryology* 98: 30-46.

DÜLL R., 1992 — Zeigerwerte von Laub- und Lebermoosen. *Scripta geobotanica* 18: 175-214.

DYMYTROVA L.V., 2009 — Epiphytic lichens and bryophytes as indicators of air pollution in Kyiv city (Ukraine). *Folia cryptogamica Estonica* 46: 33-44.

ELLIS L.T., ASTHANA A.K., VINAY SAHU, BANSAL P., NATH V., ERZBERGER P., HALLINGBÄCK T., INFANTE M., LAZAREVIĆ P., LUIS L., MEDINA R., OCHYRA R., PANDE N., PAPP B., PLÁŠEK V., SABOVLJEVIĆ M., SAWICKI J., SIM-SIM M., STEBEL A., SUÁREZ G.M., VAN ROOY J. & PHEPHU N., 2011. — New national and regional bryophyte records, 27. *Journal of bryology* 33 (2): 158-162.

FOJCIK B. & STEBEL A., 2001 — *Ecological and spatial structure of bryoflora of Katowice town*. Katowice, Upper Silesian Nature Heritage Center, Materials papers 5, 128 p. (in Polish with English summary).

FUDALI E., 1994 — Species diversity and spatial distribution of bryophytes in urban areas – a case study of the city of Szczecin. *Fragmenta floristica et geobotanica* 40 (1): 311-321.

FUDALI E., 1996 — Distribution of bryophytes in various urban-use complexes of Szczecin (NW Poland). *Fragmenta floristica et geobotanica* 41 (2): 717-745.

FUDALI E., 1997 — Changes in the Szczecin bryoflora during the past 100 years. *Fragmenta floristica et geobotanica, Series Polonica* 4: 103-119 (in Polish with English summary).

FUDALI E., 1998 — Investigations of bryophytes in Polish towns – a review of the bryological research and data. *Fragmenta floristica et geobotanica* 43: 77-101.

FUDALI E., 2012 — Recent tendencies in distribution of epiphytic bryophytes in urban areas: a Wrocław case study (South-West Poland). *Polish botanical journal* 57 (1): 231-241.

GÉHU J.-M., 1979 — *Étude phytocoenotique analytique et globale de l'ensemble des vases et prés salés et saumâtres de la façade atlantique française*. Bailleul, Université de Lille II et Station de Phytosociologie, 514 p.

GILBERT O.L., 1971 — Urban bryophyte communities in north-east England. *Transcript of the British bryological society* 6 (2): 306-316.

GOODE D.A., 1989 — Urban nature conservation in Britain. *Journal of applied ecology* 26: 859-873.

GRDOVIĆ S. & STEVANOVIĆ V., 2006 — The moss flora in the central urban area of Belgrade. *Archives of biological sciences* 58 (1): 55-59.

GREENWOOD E.F. & GEMMELL R.P., 1978 — Derelict industrial lands as a habitat for rare plants in S. Lancs. (v.c. 59) and W. Lancs. (v.c. 60). *Watsonia* 12: 33-40.

GREVEN H.C., 1992 — Changes in the Dutch bryophyte flora and air pollution. *Dissertationes botanicae* 194: 1-237.

ISERMANN M., 2007 — Diversity of bryophytes in an urban area of NW Germany. *Lindbergia* 32: 75-81.
IUCN 1978 — *The IUCN plant red data book.* Richmont, International Union for the Conservation of Nature, 543 p.
IUCN 2001 — *IUCN red list categories and criteria: version 3.1*. Gland and Cambridge, International Union for the Conservation of Nature, Species Survival Commission, 32 p.
KENT M., STEVENS R.A. & ZHANG L., 1999 — Urban plant ecology patterns and processes: a case study of the flora of the city of Plymouth, Devon, U.K. *Journal of biogeog*raphy 26: 1281-1298.
KIRMACI M. & AGCAGI E., 2009 — The bryophyte flora in the urban area of Aydin (Turkey). *International journal of botany* 5 (3): 216-225.
LARA F., LÓPEZ C. & MAZIMPAKA V. 1991 — Ecología de los briófitos urbanos en la ciudad de Segovia (España). *Cryptogamie, Bryologie-Lichénologie* 12 (4): 425-439.
LO GIUDICE R.., MAZIMPAKA V. & LARA F. 1997 — The urban bryophyte flora of the city of Enna (Sicily, Italy). *Nova Hedwigia* 64 (1-2): 249-265.
LOSTER S., 1985 — Wierzbanówka valley. 8. Evaluation of the flora by means of numerical coefficient. *Zeszyty naukowe Uniwersytetu Jagiellońskiego, Prace botaniczne* 13: 29-58 (in Polish with English summary).
MAZIMPAKA V., VINCENTE J. & RON E. 1988 — Contribución al conocimiento de la brioflora urbana de la ciudad de Madrid. *Anales del jardín botánico de Madrid* 45 (1): 61-73.
MAZIMPAKA V., LARA F., LÓPEZ-GARCIA C. 1993 — Données écologiques sur la bryoflore de la ville de Cuenca (Espagne). *Nova Hedwigia* 56 (1-2): 113-129.
MIREK Z., PIĘKOŚ-MIRKOWA H., ZAJĄC A. & ZAJĄC M., 2002 — Flowering plants and pteridophytes of Poland. A checklist. *Biodiversity of Poland* 1: 1-442.
MÜLLER F., 1993 — Studien zur Moos- und Flechtenflora der Stadt Halle/S. *Limprichtia* 1: 1-111.
OCHYRA R. & SZMAJDA P., 1981 — La cartographie bryologique en Pologne. *In*: Szweykowski J. (ed.), *New perspectives in bryotaxonomy and bryogeography*. Poznań, Uniwersytet im. Adama Mickiewicza w Poznaniu, Seria biologia 20: 105-110.
OCHYRA R., ŻARNOWIEC J. & BEDNAREK-OCHYRA H. 2003 — *Census catalogue of Polish mosses*. Kraków, Polish Academy of Sciences, Institute of Botany, 372 p.
POKORNY L., LARA F. & MAZIMPAKA V., 2006 — The bryophyte flora of the city of Trento (north Italy). *Cryptogamie, Bryologie* 27 (2): 1-20.
PYŠEK P., 1998 — Alien and native species in Central European urban floras: a quantitive comparison. *Journal of biogeog*raphy 25: 155-163.
SABOVLJEVIĆ M. & GRDOVIĆ S., 2009 — Bryophyte diversity within urban areas: case study of the city of Belgrad (Serbia). *International journal of botany* 5 (1): 85-92.
SABOVLJEVIĆ M. & SABOVLJEVIĆ A., 2009 — Biodiversity within urban areas: a case study on bryophytes of the city of Cologne (NRW, Germany). *Plant biosystems* 143 (3): 473-481.
SCHAEPE A., 1986 — Veränderungen der Moosflora von Berlin (West). *Bryophytorum bibliotheca* 33: 1-392.
SCHRADER H.J., 1994 — Die Moosflora von Braunschweig. *Limprichtia* 2: 1-98.
SCHUMACKER R. & MARTINY P., 1995 — Threatened bryophytes in Europe including Macaronesia. *In*: European Committee for Conservation of Bryophytes (ed.), *Red Data Book of European Bryophytes*. Trondheim, University of Trondheim, pp. 29-193.
SEAWARD M.R.D., 1979 — Lower plants and the urban landscape. *Urban ecology* 4: 217-225.
SOKAL R.R. & ROHLF F.J., 1995 — *Biometry: the principles and practice of statistics in biological research*. New York, W.H. Freeman, 887 p.
SÖDERSTRÖM L., 1992 — Invasions and range expansions and contractions of bryophytes. *In*: Bates J.W. & Farmer A.M. (eds.), *Bryophytes and Lichens in a changing environment*. Oxford, Clarendon Press, pp. 131-158.
STARFINGER V. & SUKOPP H., 1994 — Assessment of urban biotopes for nature conservation. *In*: Cook E.A. & Van Lier H.N. (eds.), *Landscape planning and ecological networks*. Amsterdam, Elsevier, pp. 89-115.
STEBEL A., 1997a — Towards the protection of the locality of *Discelium nudum* in the Silesian Upland. *Chrońmy przyrodę ojczystą* 53 (3): 91-93 (in Polish with English summary).
STEBEL A., 1997b — Bryophytes of the Rybnik Coal District (S Poland). *Fragmenta floristica et geobotanica, Series Polonica* 4: 121-233 (in Polish with English summary).
STEBEL A. & OCHYRA R., 1997 — A second recent record of *Trematodon ambiguus* (Musci, Bruchiaceae) in Poland. *Fragmenta floristica et geobotanica* 42 (1): 182-184.
STEBEL A., 2010 — Rediscovery of *Orthotrichum rogeri* Brid. (Bryophyta) in Poland. *Opole scientific society nature journal* 43: 23-27.
STEBEL A., FOJCIK B., KLAMA H. & ŻARNOWIEC J., 2011 — The Red list of threatened bryophytes of Silesian Voivodship. Katowice, Upper Silesian Nature Heritage Center, *Reports opinions* 6: 7-104 (in Polish).

STEBEL A., VIRCHENKO V., PLÁŠEK V., OCHYRA R. & BEDNAREK-OCHYRA H., 2012 — Range extension of *Orthodicranum tauricum* (Bryophyta, Dicranaceae) in central-east Europe. *Polish botanical journal* 57 (1): 119-128.

STEBEL A., 2013 — Distribution of *Callicladium haldanianum* (Bryophyta, Hypnaceae) in Poland. *Polish botanical journal* 58 (2): 593-603.

SUDNIK-WÓJCIKOWSKA B., 1998 — Flora synanthropization and anthropopressure zones in a large urban agglomeration (exemplified by Warsaw). *Flora* 180: 259-265.

SUKOPP H., 1992 — Urban ecosystems. *Journal of the natural history museum and institute*, *Chiba* 2 (1): 53-62.

SUKOPP H. & WITTIG R., 1993 — *Stadtökologie*. Stuttgart, Gustav Fischer Verlag, 402 p.

SZAFLARSKI J., 1976 — Środowisko geograficzne Katowic. *In*: Mrozek W. (ed.), *Katowice – ich dzieje i kultura na tle regionu*. Warszawa, Wydawnictwo Arkady, pp. 8-38 (in Polish).

TOKARSKA-GUZIK B., 1991 — Glass works heap in Jaworzno-Szczakowa (district of Katowice) as the mainstay of the disappearing plant species in the town. *Kształtowanie środowiska geograficznego i ochrona przyrody na obszarach uprzemysłowionych i zurbanizowanych* 3: 39-42 (in Polish with English summary).

VANDERPOORTEN A., 1997 — A bryological survey of the Brussels Capital Region (Belgium). *Scripta botanica Belgica* 14: 1-83.

WANIA A., KÜHN I. & KLOTZ S., 2006 — Plant richness patterns in agricultural and urban landscapes in Central Germany – spatial gradients of species richness. *Landscape and urban planning* 75: 97-110.

ŻARNOWIEC J., 1996 — The bryoflora of urban areas √ a floristic-ecological case study of Oświęcim tows (S Poland). *Fragmenta floristica et geobotanica* 41 (1): 355-377.

ŻARNOWIEC J., STEBEL A. & OCHYRA R., 2004 — Threatened moss species in the Polish Carpathians in the light of a new Red-list of mosses in Poland. *In*: Stebel A. & Ochyra R. (eds.), *Bryological studies in the Western Carpathians*. Poznań, Sorus, pp 9-28.

APPENDIX 1

Checklist of moss flora of the Katowice town (with one asterisk – species strictly protected in Poland; with two asterisks – species partially protected; according to the Disposition by the Minister of Environment from 2012).

AMBLYSTEGIACEAE: *Amblystegium juratzkanum, A. radicale*, A. serpens, Anacamptodon splachnoides*, Calliergon cordifolium, Campylidium calcareum, Campylium polygamum, C. stellatum, Drepanocladus aduncus, D. polycarpos, Leptodictyum humile*, L. riparium, Sanionia uncinata, Straminergon stramineum, Warnstorfia exannulata, W. fluitans, W. pseudostraminea.*
AULACOMNIACEAE: *Aulacomnium androgynum, A. palustre**.*
BARTRAMIACEAE: *Philonotis caespitosa*, Ph. fontana.*
BRACHYTHECIACEAE: *Brachytheciastrum velutinum, Brachythecium albicans, B. campestre, B. mildeanum, B. rivulare, B. rutabulum, B. salebrosum, Cirriphyllum piliferum, Eurhynchium angustirete**, E. striatum**, Homalothecium sericeum, Kindbergia praelonga, Oxyrrhynchium hians, O. schleicheri, O. speciosum, Pseudoscleropodium purum**, Rhynchostegium murale, Sciuro-hypnum oedipodium, S. plumosum, S. populeum, S. reflexum, S. starkei.*
BRUCHIACEAE: *Trematodon ambiguus.*
BRYACEAE: *Bryum argenteum, B. caespiticium, B. dichotomum, B. klinggraeffii, B. pallescens, B. pseudotriquetrum, B. rubens, Leptobryum pyriforme, Pohlia annotina, P. bulbifera, P. camptotrachela, P. melanodon, P. nutans, P. proligera, P. wahlenbergii, Rhodobryum roseum, Rosulabryum capillare, R. moravicum.*
CINCLIDIACEAE: *Rhizomnium punctatum.*
CLIMACIACEAE: *Climacium dendroides**.*
CRATONEURACEAE: *Cratoneuron filicinum.*
DICRANACEAE: *Campylopus introflexus*, *Dicranella cerviculata, D. heteromalla, D. rufescens*, *D. schreberiana, D. staphylina, D. varia, Dicranum polysetum**, D. scoparium**, Orthodicranum flagellare, O. montanum, O. tauricum.*
DIPHYSCIACEAE: *Diphyscium foliosum.*
DISCELIACEAE: *discelium nudum*.*
DITRICHACEAE: *Ceratodon purpureus, Pleuridium subulatum.*
ENCALYPTACEA: *Encalypta streptocarpa.*
FISSIDENTACEAE: *Fissidens bryoides, F. exilis, F. taxifolius.*
FONTINALACEAE: *Fontinalis antipyretica.*
FUNARIACEAE: *Funaria hygrometrica*, *Physcomitrella patens*, *Physcomitrium pyriforme.*
GRIMMIACEAE: *Codriophorus acicularis*, *Dryptodon muehlenbeckii, D. pulvinatus, Schistidium apocarpum* (s.l.), *Niphotrichum canescens.*
HELODIACEAE: *Helodium blandowii*.*
HYLOCOMIACEAE: *Hylocomiadelphus triquetrus**, Hylocomium splendens**, Pleurozium schreberi**, Rhytidiadelphus squarrosus**.*
HYPNACEAE: *Callicladium haldanianum, Calliergonella cuspidata**, Herzogiella seligeri, Hypnum cupressiforme, H. lindbergii, H. pallescens, Platygyrium repens, Pseudotaxiphyllum elegans, Ptilium crista-castrensis, Pylaisia polyantha.*
LESKEACEAE: *Leskea polycarpa.*
LEUCOBRYACEAE: *Leucobryum glaucum**.*
MNIACEAE: *Mnium hornum.*
ORTHODONTIACEAE: *Orthodontium lineare.*
ORTHOTRICHACEAE: *Orthotrichum affine, O. anomalum, O. cupulatum, O. diaphanum, O. obtusifolium, O. patens, O. pumilum, O. rogeri*, O. speciosum, O. stramineum, O. striatum, Ulota bruchii*, U. crispa*.*
PLAGIOMNIACEAE: *Plagiomnium affine, P. cuspidatum, P. elatum, P. ellipticum, P. medium, P. rostratum, P. undulatum.*
PLAGIOTHECIACEAE: *Plagiothecium curvifolium, P. denticulatum, P. laetum, P. latebricola, P. nemorale, P. ruthei, P. succulentum.*
POLYTRICHACEAE: *Atrichum angustatum, A. tenellum, A. undulatum, Oligotrichum hercynicum, Pogonatum aloides, P. urnigerum, Polytrichastrum formosum*, *P. longisetum, Polytrichum commune**, P. juniperinum, P. piliferum.*
POTTIACEAE: *Aloina rigida, Barbula convoluta, B. unguiculata, Bryoerythrophyllum recurvirostrum, Didymodon fallax, D. luridus, D. rigidulus, D. tophaceus, Pseudocrossidium hornschuchianum, Syntrichia latifolia*, S. ruralis, Tortula acaulon, T. modica, T. muralis, T. truncata, Weissia controversa.*
SELIGERIACEAE: *Dicranoweisia cirrata.*
SPHAGNACEAE: *Sphagnum angustifolium*, S. capillifolium*, S. compactum**, *S. cuspidatum*, S. denticulatum**, *S. fallax**, S. fimbriatum*, S. flexuosum*, S. girgensohnii*, S. inundatum*, S. magellanicum*, S. palustre*, S. papillosum**, *S. riparium*, S. russowii**, *S. squarrosum**, S. subsecundum**, *S. teres*, S. warnstorfii*.*
TETRAPHIDACEAE: *Tetraphis pellucida.*
THUIDIACEAE: *Abietinella abietina**, Thuidium assimile**, T. delicatulum**, T. tamariscinum**.*